

# Comparison of Abdominal Muscle Activity During a Single-Legged Hold in the Hook-Lying Position on the Floor and on a Round Foam Roll

Su-Jung Kim, MSc, PT\*; Oh-Yun Kwon, PhD, PT\*; Chung-Hwi Yi, PhD, PT\*; Hye-Seon Jeon, PhD, PT\*; Jae-Seop Oh, PhD, PT†; Heon-Seock Cynn, PhD, PT\*; Jong-Hyuck Weon, PhD, PT‡

\*Department of Rehabilitation Therapy, Graduate School, Yonsei University, Kangwon-do, South Korea;

†Department of Physical Therapy, Inje University, Gyeongsangnam-do, South Korea; ‡Department of Rehabilitation Therapy, Wonju Christian Hospital, Kangwon-do, South Korea

**Context:** To improve trunk stability or trunk muscle strength, many athletic trainers and physiotherapists use various types of unstable equipment for training. The round foam roll is one of those unstable pieces of equipment and may be useful for improving trunk stability.

**Objective:** To assess the effect of the supporting surface (floor versus round foam roll) on the activity of abdominal muscles during a single-legged hold exercise performed in the hook-lying position on the floor and on a round foam roll.

**Design:** Crossover study.

**Setting:** University research laboratory.

**Patients or Other Participants:** Nineteen healthy volunteers (11 men, 8 women) from a university population.

**Intervention(s):** The participants were instructed to perform a single-legged hold exercise while in the hook-lying position on the floor (stable surface) and on a round foam roll (unstable surface).

**Main Outcome Measure(s):** Surface electromyography (EMG) signals were recorded from the bilateral rectus abdominis, internal oblique, and external oblique muscles. Dependent variables were examined with a paired *t* test.

**Results:** The EMG activities in all abdominal muscles were greater during the single-legged hold exercise performed on the round foam roll than on the stable surface.

**Conclusions:** The single-legged hold exercise in the hook-lying position on an unstable supporting surface induced greater abdominal muscle EMG amplitude than the same exercise performed on a stable supporting surface. These results suggest that performing the single-legged hold exercise while in the hook-lying position on a round foam roll is useful for activating the abdominal muscles.

**Key Words:** trunk stability, low back pain, electromyography, injury prevention

## Key Points

- The unilateral single-legged hold exercise performed on a round foam roll resulted in greater abdominal muscle activation than did the same exercise performed on a stable surface.
- During this exercise on a round foam roll, activation of the transversus abdominis/internal oblique muscles was greater on the contralateral side, but activation of the rectus abdominis and external oblique muscles was greater on the ipsilateral side.

Trunk stability is essential to prevent lumbar compensatory motion<sup>1,2</sup> and to reduce the intensity<sup>3–5</sup> and recurrence rate<sup>6</sup> of low back pain. Trunk stability is maintained by passive, active, and neural control subsystems.<sup>7</sup> The trunk muscles are coactivated through integrated active and neural control subsystems to stabilize the trunk and spinal segment.<sup>7–9</sup>

Unlike the cervical spine, the lumbar spine lacks flexor muscles just anterior to the vertebral body; thus, to achieve trunk stability, it is essential to improve abdominal muscle activity and coordination.<sup>8,9</sup> Previous authors have suggested that trunk stability can be improved with pelvic tilt,<sup>10</sup> abdominal hollowing,<sup>10</sup> abdominal bracing,<sup>10</sup> curl-up,<sup>11</sup> bridging,<sup>12</sup> and “dead-bug” exercises.<sup>11</sup> Unstable surfaces, such as a gym ball or wobble board, have been

used to increase the difficulty level of trunk stability exercises.<sup>13</sup> Previous researchers<sup>13–15</sup> compared the activity of the trunk and abdominal muscles on unstable and stable surfaces and demonstrated that abdominal muscle activity was greater on the unstable surface. Rectus abdominis (RA) and external oblique (EO) activity was greater when curl-up exercises were performed on unstable surfaces compared with stable surfaces,<sup>13</sup> and Marshall and Murphy<sup>14</sup> reported that activity of the RA muscle was greater during exercise on the Swiss ball than on a stable surface. Similarly, Behm et al<sup>15</sup> found that activity of the upper lumbar erector spinae, lumbosacral erector spinae, transversus abdominis (TrA), and internal oblique (IO) muscles during the chest press exercise was greater on an unstable surface than on a stable surface.

A unilateral, active straight-leg raise in supine position can be used to test lumbar spine stability in the supine position<sup>1</sup>; lumbar axial rotation may occur.<sup>1</sup> Furthermore, an asymmetric load on the trunk induced by a unilateral single-legged hold exercise on an unstable round foam roll causes more lumbar axial rotation,<sup>16</sup> but abdominal muscle activity in this circumstance has not been reported. Therefore, the aim of our study was to compare the abdominal muscle activity measured during a unilateral single-legged hold exercise in a hook-lying position on the floor and on a round foam roll. We hypothesized that performing the exercise on a round foam roll would induce greater muscle activity than would the same maneuver on the floor.

METHODS

Participants

Nineteen volunteers participated in this study (11 men, 8 women; mean age=23.2±2.3 years, height=168.2±7.3 cm, weight=61.3±9.7 kg). Volunteers were included if they had no history of low back pain or lower extremity injuries, such as sprains or fractures, and were able to maintain a 5-second single-legged hold on the floor (stable condition) and on a round foam roll (unstable condition). They were excluded if they had a prior low back or lower extremity surgery, leg-length discrepancy, marked kyphosis or scoliosis, or neurologic disease. The dominant leg was determined by asking the participant to kick a soccer ball; the kicking leg was determined to be the dominant leg.<sup>17–19</sup> All participants were right-leg dominant. The university’s institutional review board approved the study, and all volunteers provided written informed consent before the study began.

Electromyography

Surface electromyography (EMG) was used to measure muscle activity. The EMG data were collected bilaterally from the RA, EO, and TrA/IO muscles (Figure 1). Electrode placement for each muscle is described in Table 1.<sup>20,21</sup> Electrode placement for the TrA/IO was based on previous reports.<sup>22,23</sup> McGill et al<sup>22</sup> stated that the EMG signal obtained from an electrode inferior to the anterior-superior iliac spine represents the combined activity of the TrA and IO. In an ultrasonic imaging study of 10 cadavers, Marshall and Murphy<sup>23</sup> confirmed that the TrA and IO muscles were fused 2 cm medial and inferior to the anterior-superior iliac spine and reported no overlap of the EO muscle.

The skin was shaved, sanded, and swabbed with alcohol-soaked cotton before electrode placement to minimize skin resistance.<sup>2</sup> A small amount of electrode gel was applied to silver chloride electrodes (DE-3.1 double differential electrode; Delsys, Inc, Boston, MA), which were then applied to the skin.<sup>2</sup> The reference electrode was applied to the lateral malleolus of the dominant leg. The EMG data were collected using a data acquisition system (model MP100WSW; Biopac Systems, Inc, Goleta, CA).<sup>2</sup>

The analog signals were converted to digital signals, and the converted signals were processed for analysis using Acqknowledge software (version 3.8.1; Biopac Systems, Inc). The raw EMG signal was recorded at a sampling rate of 1000 Hz. A bandpass filter of 20–450 Hz was used to eliminate movement artifact, and a 60-Hz notch filter was used to minimize electrical noise.<sup>2,20</sup> The EMG signal was processed to the root mean square (RMS) using a moving window of 50 milliseconds and analyzed as an ASCII file.

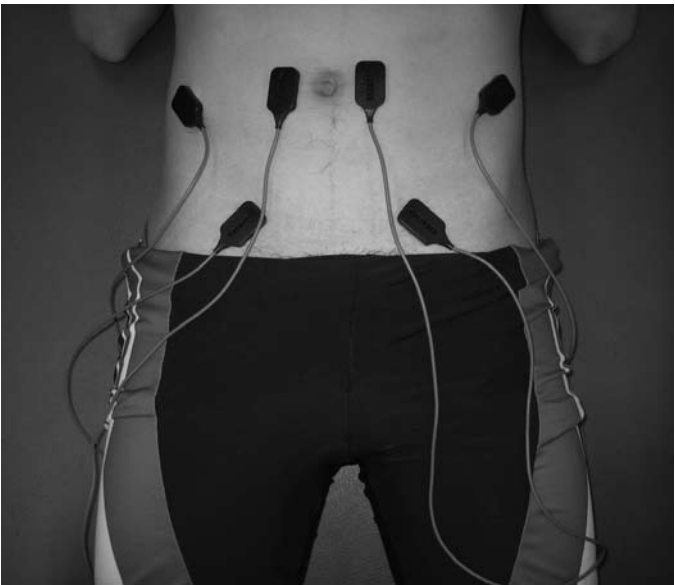


Figure 1. Placement of electrodes.

Table 1. Electrode Placement on Muscles

Muscle	Electrode Placement
Rectus abdominis	2 cm lateral to the umbilicus <sup>20</sup>
External oblique	45° obliquely parallel to a line connecting the most inferior point of the costal margin of the ribs and the contralateral pubic tubercle above the anterior-superior iliac spine near the level of the umbilicus <sup>21</sup>
Transversus abdominis/ internal oblique	Midpoint between the anterior-superior iliac spine and the pubic tubercle <sup>21</sup>

For normalization, the RMS of a 5-second maximal voluntary isometric contraction (MVIC) was measured 3 times for each muscle in the standardized position (Table 2).<sup>24</sup> The average RMS of 3 measurements was used to determine the MVIC of each muscle.

For the single-legged hold measurement, the data were collected during a 5-second period. Data from the initial 1 second and final 1 second were excluded; thus, 3 seconds of data were analyzed. A 1-minute rest period was provided between measurements to prevent muscle fatigue. The normalized muscle activity was expressed as a percentage of the MVIC (%MVIC=[average RMS on the floor or on a round foam roll/average RMS of 3 MVICs]×100).

Procedures

Each participant was instructed to lie supine on either the floor or a round foam roll (15.2×91.4 cm; Sammons Preston Rolyan, Bolingbrook, IL). Using a universal manual goniometer (Sammons Preston Rolyan), the principal investigator (S.J.K.) measured hip and knee joint angles to place the participant in the hook-lying position. The hip and knee joints bilaterally were flexed to 45° and 70°, respectively, so that the lower back was flat on the floor or the round foam roll. The hip and knee joint angles of the dominant leg (supporting leg) were maintained at 45° and 70°, respectively, during the single-legged hold of

**Table 2. Standardized Positions for Measurement of Maximal Voluntary Isometric Contractions**

Muscle	Starting Position	Measurement Position
Rectus abdominis	Body supine with hips and knees straight and strapped with a belt	Resisted curl-up with maximal manual isometric resistance applied to the shoulders
Contralateral <sup>a</sup> external oblique Ipsilateral <sup>b</sup> transversus abdominis/ internal oblique	Body supine with hips and knees straight and strapped with a belt	Resisted crossed curl-up with contralateral shoulder toward ipsilateral shoulder and maximal manual isometric resistance to the contralateral shoulder
Ipsilateral external oblique Contralateral transversus abdominis/ internal oblique	Body supine with hips and knees straight and strapped with a belt	Resisted crossed curl-up with ipsilateral shoulder toward contralateral shoulder and maximal manual isometric resistance to the ipsilateral shoulder

<sup>a</sup>Side of the supporting leg.

<sup>b</sup>Side of the lifting leg.

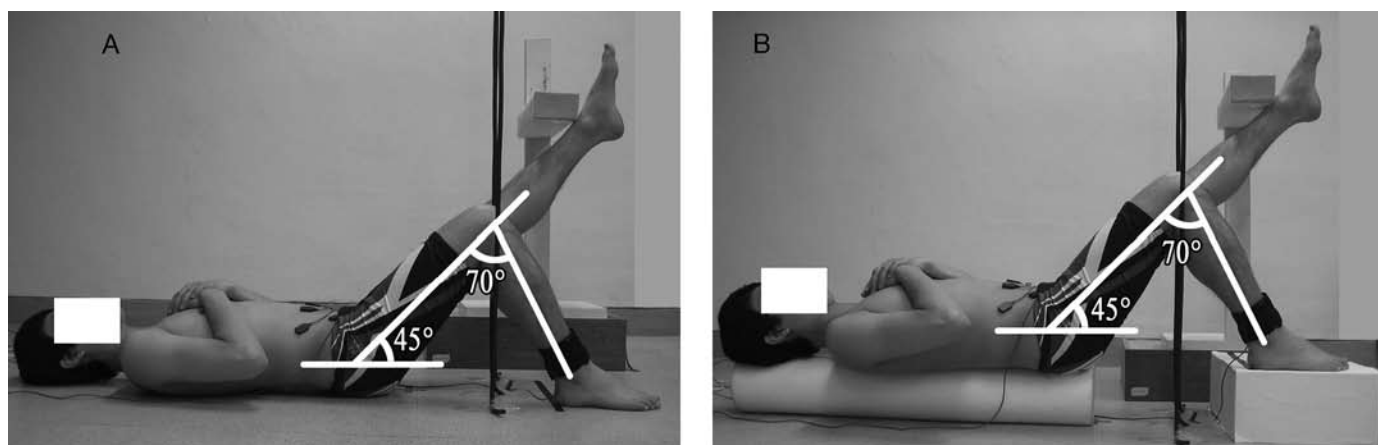
the nondominant leg, in both the floor and the round foam roll conditions (Figure 2). A target bar was placed so that the participant's ankle would touch it with full extension of the knee joint. Elastic guides were aligned with the lower extremity to limit abduction of the hip and adduction of both legs (Figure 3). When the examiner observed a deviation from the vertical elastic guides resulting from excessive pressure, the data were discarded. A small box (30.5×40.6×15.2 cm) the same height as the round foam roll was placed under both feet during knee extensions performed on the round foam roll; this was to ensure that the hip and knee joint angles were the same as those for knee extensions performed on the floor (Figure 2B).

The familiarization period consisted of approximately 1 hour (25-minute session with 10-minute break between sessions). During the familiarization period, the participant was instructed to raise the nondominant lower limb until he or she touched the target bar on the dorsum of the foot without pressing the vertical elastic guide. The participant was instructed to use the fingertips of both hands to touch the floor and maintain balance without falling off the foam roll. The amount of support from the fingertips decreased gradually as the participant became familiar with the foam roll. The familiarization period was completed when the participant was able to maintain 3 consecutive 5-second single-leg holds with 1-minute rest periods without fatigue on a round foam roll. All participants felt comfortable, and none reported fatigue after the familiarization period. A 15-minute rest period after familiarization was allowed before data collection.

Performance of the single-leg hold was randomized by selecting from the numbers 1 and 2 (number 1, floor; number 2, round foam roll). The participant extended the nondominant knee joint until the ankle joint touched the target bar and then sustained an isometric contraction for 5 seconds. During the unstable condition, the participant was asked to lie on the round foam roll. The head and vertebral column were aligned to the longitudinal axis of the round foam roll. Then the participant was asked to extend the nondominant knee without moving the hip. He or she was instructed to hold the nondominant leg steady at the target position without falling off the round foam roll. Data were collected when the participant maintained the test position while holding the leg within the vertical elastic guides and without loss of balance. Three trials were performed with a 1-minute rest period between trials. A 3-minute rest period was provided between conditions when changing from one supporting surface to the other to minimize muscle fatigue.<sup>24</sup>

### Statistical Analyses

A paired *t* test with Bonferroni adjustment was used, with the level of significance set at  $P=.008$  (.05/6) to compare muscle activity generated during exercise performed on the floor and the round foam roll. The effect size was calculated using the pooled SD. Data were processed with SPSS (version 12.0; SPSS Inc, Chicago, IL). The percentage increment of muscle activity across the supporting surface was determined ( $[\text{muscle activity difference between the floor and the round foam roll}/\text{muscle activity on the floor}] \times 100$ ).



**Figure 2. Single-legged hold exercise. A, On the floor. B, On a round foam roll.**



**Figure 3.** Target bar position and knee position guides.

## RESULTS

We observed greater abdominal muscle activity during a single-legged hold on the round foam roll than on the floor (Table 3). The percentage increment of muscle activity was 88.08% in the contralateral RA ( $P_{\text{adj}} = .003$ ), 107.81% in the ipsilateral RA ( $P_{\text{adj}} < .001$ ), 51.67% in the contralateral EO ( $P_{\text{adj}} = .003$ ), 96.59% in the ipsilateral EO ( $P_{\text{adj}} < .001$ ), 172.24% in the contralateral TrA/IO ( $P_{\text{adj}} < .001$ ), and 118.88% in the ipsilateral TrA/IO ( $P_{\text{adj}} = .001$ ) (Table 4).

**Table 3. Comparison of Abdominal Muscle Activity (% of Maximal Voluntary Isometric Contraction) During Single-Legged Hold Exercise on Stable and Unstable Surfaces**

Muscle	Supporting Surface				P Value	Effect Size
	Floor		Round Foam Roll			
	Mean ± SD	95% Confidence Interval	Mean ± SD	95% Confidence Interval		
Contralateral <sup>a</sup> rectus abdominis	14.12 ± 5.91	11.27, 16.97	22.54 ± 9.68	17.87, 27.20	.003	1.05
Ipsilateral <sup>b</sup> rectus abdominis	13.00 ± 5.77	10.22, 15.78	24.27 ± 11.63	18.66, 29.87	<.001	1.23
Contralateral external oblique	22.96 ± 10.28	18.00, 27.92	34.06 ± 19.68	24.57, 43.54	.003	0.70
Ipsilateral external oblique	25.38 ± 10.92	20.11, 30.64	45.34 ± 19.51	35.94, 54.74	<.001	1.26
Contralateral transversus abdominis/internal oblique	16.21 ± 13.54	9.69, 22.74	35.21 ± 17.34	26.86, 43.57	<.001	1.22
Ipsilateral internal transversus abdominis/internal oblique	14.68 ± 7.94	10.86, 18.51	28.44 ± 16.37	20.55, 36.34	.001	1.07

<sup>a</sup>Side of the supporting leg.

<sup>b</sup>Side of the lifting leg.

## DISCUSSION

We compared the amplitude of EMG activity of bilateral abdominal muscles during a single-legged hold exercise performed on the floor and on a round foam roll. The single-legged hold exercise on a round foam roll led to greater EMG activity levels in the bilateral RA, EO, and TrA/IO muscles than did the floor condition.

Two possible explanations exist for greater muscle activity on the round foam roll. First, because of the instability of the round foam roll supporting surface, muscles crossing the abdominal area need to contract together to maintain stability during the single-leg hold. Vera-Garcia et al<sup>13</sup> reported that RA and EO muscle activity on a gym ball (unstable surface) was greater than that on a stable bench during the curl-up exercise. Marshall and Murphy<sup>14</sup> reported that the RA and TrA/IO muscle activity on a gym ball was greater than on a stable surface during a press-up exercise. Our findings are in accordance with those of previous researchers demonstrating greater muscle activity on unstable surfaces than on stable surfaces.<sup>13–15</sup> Second, when participants lie on a round foam roll as compared with the floor, the contact area is smaller. Santos and Aruin<sup>25</sup> demonstrated that maintaining the center of gravity within a reduced base of support was more challenging and necessitated EO muscle contraction. They also noted that muscle coactivation can lead to increased joint stiffness, assisting counterbalancing body perturbations.<sup>25</sup> Therefore, lying on a smaller base of support on a round foam roll could have induced more abdominal muscle activity than lying on the floor.

During a single-legged hold on a round foam roll, bilateral TrA/IO muscle activity was greater than that of the RA and EO. A TrA/IO contraction increases intra-abdominal pressure; together these factors play key roles in maintaining lumbar segmental stabilization because the IO muscle blends with the lateral raphe of the thoracolumbar fascia.<sup>1,9,22,23,26,27</sup> During the single-legged hold, trunk stability is further challenged by the unstable surface, and bilateral TrA/IO muscle activity was thought to be induced to maintain stability. Thus, the single-legged hold performed on a round foam roll increases abdominal activity, including bilateral contraction of the TrA/IO, a lumbar stabilizer.<sup>2</sup>

Although all abdominal muscle activity increased during the single-legged hold on the round foam roll, it is interesting that the muscle activity of the contralateral TrA/IO was greater than that of the ipsilateral TrA/IO, whereas for the RA

**Table 4. Percentage Increments of Muscle Activity Across the Supporting Surface**

Muscle(s)	Increment, % <sup>a</sup>
Contralateral <sup>b</sup> rectus abdominis	88.08
Ipsilateral <sup>c</sup> rectus abdominis	107.81
Contralateral external oblique	51.67
Ipsilateral external oblique	96.59
Contralateral transversus abdominis/internal oblique	172.24
Ipsilateral transversus abdominis/internal oblique	118.88

<sup>a</sup>(Difference in muscle activity between the floor and a round foam roll/muscle activity on the floor)×100.

<sup>b</sup>Side of the supporting leg.

<sup>c</sup>Side of the lifting leg.

and EO, the ipsilateral muscle showed a greater level of activity. These results are also consistent with previous findings that demonstrated greater activity of the contralateral TrA/IO and ipsilateral EO during a single-leg lift in 4-point kneeling,<sup>26</sup> which created a rotation moment toward the side of the single-legged lift. Thus, a stable pelvis and spine posture arose from cooperation of the contralateral IO and the ipsilateral EO. It is possible that increased contralateral IO activity was caused by counteracting movement induced by the single-legged hold on an unstable surface. Behm et al<sup>15</sup> reported that the unilateral chest press using a dumbbell was more effective in activating all trunk stabilizers than was a bilateral arm exercise. They suggested that the unbalanced movement of a unilateral arm outside the base of support would result in a destabilizing torque that was counteracted by a contralateral trunk muscle contraction.<sup>15</sup> Liebensohn et al<sup>1</sup> measured the lumbar axial rotation during active straight-leg raising in asymptomatic volunteers using an electromagnetic tracking device and found 5.4° of lumbar axial rotation with no abdominal bracing. With the single-legged hold of the ipsilateral side performed on a round foam roll in our study, the roll would rotate to the ipsilateral side secondary to the tendency toward lumbar rotation that has been observed previously<sup>1</sup> in the straight-leg raise and increased rotation toward the side of the single-legged hold. Therefore, we believe that to counterbalance the ipsilateral rotation and maintain trunk stability, the contralateral TrA/IO, EO, and RA cocontract to produce a contralateral rotation movement to maintain trunk balance and avoid falling.<sup>15</sup> In particular, the contralateral TrA/IO seemed to be activated more as a lumbopelvic stabilizer. Because instability cannot be overcome by the contralateral TrA/IO, the ipsilateral TrA/IO begins to contract along with the contralateral TrA/IO to counterbalance the rotation force toward the ipsilateral side and to improve lumbar stability by increasing intra-abdominal pressure via bilateral TrA/IO contractions.<sup>1,27–30</sup> These findings are also thought to be elicited by a diagonal trunk rotation moment; the ipsilateral EO and contralateral TrA/IO contract together to counterbalance the ipsilateral rotation moment on a round foam roll. However, we think further research is needed to clarify the exact mechanism for greater contralateral than ipsilateral TrA/IO activity.

In our study, ipsilateral RA and EO muscle activity was greater than that on the contralateral side. This greater ipsilateral RA and EO muscle activity can be attributed to their synergistic roles in minimizing compensatory pelvic rotation.<sup>31</sup> When the single-legged hold is maintained on a round foam roll, the hip flexors contract isometrically. This contraction of

the hip flexors may tend to tilt the pelvis anteriorly. Therefore, the ipsilateral RA and EO are likely to contract synergistically for pelvic stability.

Some authors have demonstrated a leg dominance effect on the strength of the hip muscle,<sup>18</sup> joint torque, and ground reaction force during a squat.<sup>32</sup> Conversely, squat strength<sup>17</sup> and postural control (eg, sway area and sway path length in single-legged standing)<sup>19</sup> did not differ between the dominant and nondominant legs.<sup>19</sup> In our study, all participants were right-leg dominant, so there may be a leg-dominance effect on trunk muscle activity. Future study is needed to investigate the effect of leg dominance on abdominal muscle activity during the single-legged hold on the round foam roll. We recruited healthy volunteers without a history of low back pain or lower extremity injury; thus, our findings cannot be generalized to patient populations. We did not directly measure the lumbopelvic rotation angle, and further study is needed to examine the lumbopelvic rotation during the single-legged hold task. The test position in this study consisted of the participants lying on their backs, so it was almost impossible to position electrodes for measuring the EMG activity of the back muscles. McGill et al<sup>22</sup> stated that the surface electrode position over the IO and TrA demonstrated the fine-wire activity of the TrA within approximately 15% of the contraction amplitude. To our knowledge, no authors have reported a standard method of measuring the MVIC of the TrA with surface EMG. This limitation might have affected the results of the TrA/IO muscle activity in our study. Our investigation should be replicated in patient populations to generalize the findings, and longitudinal studies should be performed to determine the long-term effect of the single-legged-hold exercise on a round foam roll on muscle activity.

## CONCLUSIONS

The activity of all the abdominal muscles measured increased during a unilateral single-legged hold exercise performed on a round foam roll. This finding suggests that performing the single-legged hold exercise on an unstable round foam roll is more effective in recruiting abdominal muscle activity than is exercise on a stable surface.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Liebensohn C, Karpowicz AM, Brown SH, Howarth SJ, McGill SM. The active straight leg raise test and lumbar spine stability. *PM R*. 2009;1(6):530–535.
2. Cynn HS, Oh JS, Kwon OY, Yi CH. Effects of lumbar stabilization using a pressure biofeedback unit on muscle activity and lateral pelvic tilt during hip abduction in sidelying. *Arch Phys Med Rehabil*. 2006;87(11):1454–1458.
3. O'Sullivan PB, Phytz GD, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine (Phila Pa 1976)*. 1997;22(24):2959–2967.
4. Rydeard R, Leger A, Smith D. Pilates-based therapeutic exercise: effect on subjects with nonspecific chronic low back pain and functional disability: a randomized controlled trial. *J Orthop Sports Phys Ther*. 2006;36(7):472–484.

5. Suni J, Rinne M, Natri A, Statistisian MP, Parkkari J, Alaranta H. Control of the lumbar neutral zone decreases low back pain and improves self-evaluated work ability: a 12-month randomized controlled study. *Spine (Phila Pa 1976)*. 2006;31(18):E611–E620.
6. Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine (Phila Pa 1976)*. 2001;26(11):E243–E248.
7. Panjabi MM. The stabilizing system of the spine, part I: function, dysfunction, adaptation, and enhancement. *J Spinal Disord*. 1992;5(4):383–389.
8. Cholewicki J, Panjabi MM, Khachatryan A. Stabilizing function of trunk flexor-extensor muscles around a neutral spine posture. *Spine (Phila Pa 1976)*. 1997;22(19):2207–2212.
9. Gardner-Morse MG, Stokes IA. The effects of abdominal muscle coactivation on lumbar spine stability. *Spine (Phila Pa 1976)*. 1998;23(1):86–91.
10. Richardson C, Jull G, Toppenberg R, Comerford M. Techniques for active lumbar stabilisation for spinal protection: a pilot study. *Aust J Physiother*. 1992;38(2):105–112.
11. McGill SM, Karpowicz A. Exercises for spine stabilization: motion/motor patterns, stability progressions, and clinical technique. *Arch Phys Med Rehabil*. 2009;90(1):118–126.
12. Stevens VK, Bouche KG, Mahieu NN, Coorevits PL, Vanderstraeten GG, Danneels LA. Trunk muscle activity in healthy subjects during bridging stabilization exercises. *BMC Musculoskelet Disord*. 2006;7:75.
13. Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. *Phys Ther*. 2000;80(6):564–569.
14. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. *Arch Phys Med Rehabil*. 2005;86(2):242–249.
15. Behm DG, Leonard AM, Young WB, Bonsey WA, MacKinnon SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. *J Strength Cond Res*. 2005;19(1):193–201.
16. Creager CC. *Therapeutic Exercises Using Foam Rollers*. Berthoud, CO: Executive Physical Therapy Inc; 1996:193.
17. McCurdy K, Langford G. Comparison of unilateral squat strength between the dominant and non-dominant leg in men and women. *J Sports Sci Med*. 2005;4(3):153–159.
18. Jacobs C, Uhl TL, Seeley M, Sterling W, Goodrich L. Strength and fatigability of the dominant and nondominant hip abductors. *J Athl Train*. 2005;40(3):203–206.
19. Hoffman M, Schrader J, Applegate T, Kocaja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *J Athl Train*. 1998;33(4):319–322.
20. Cram JR, Kasman GS, Holtz J. *Introduction to Surface Electromyography*. Gaithersburg, MD: Aspen Publishers Inc; 1998:50–55, 343–345.
21. Escamilla RF, McTaggart MS, Fricklas EJ, et al. An electromyographic analysis of commercial and common abdominal exercises: implications for rehabilitation and training. *J Orthop Sports Phys Ther*. 2006;36(2):45–57.
22. McGill S, Juker D, Kropf P. Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. *J Biomech*. 1996;29(11):1503–1507.
23. Marshall P, Murphy B. The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *J Electromyogr Kinesiol*. 2003;13(5):477–489.
24. Dankaerts W, O'Sullivan PB, Burnett AF, Straker LM, Danneels LA. Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. *J Electromyogr Kinesiol*. 2004;14(3):333–342.
25. Santos MJ, Aruin AS. Effects of lateral perturbations and changing stance conditions on anticipatory postural adjustment. *J Electromyogr Kinesiol*. 2009;19(3):532–541.
26. Stevens VK, Vleeming A, Bouche KG, Mahieu NN, Vanderstraeten GG, Danneels LA. Electromyographic activity of trunk and hip muscles during stabilization exercises in four-point kneeling in healthy volunteers. *Eur Spine J*. 2007;16(5):711–718.
27. Hodges PW, Eriksson AE, Shirley D, Gandevia SC. Intra-abdominal pressure increases stiffness of the lumbar spine. *J Biomech*. 2005;38(9):1873–1880.
28. Teyhen DS, Williamson JN, Carlson NH, et al. Ultrasound characteristics of the deep abdominal muscles during the active straight leg raise test. *Arch Phys Med Rehabil*. 2009;90(5):761–767.
29. Cholewicki J, Ivancic PC, Radebold A. Can increased intra-abdominal pressure in humans be decoupled from trunk muscle co-contraction during steady state isometric exertions? *Eur J Appl Physiol*. 2002;87(2):127–133.
30. Cholewicki J, Juluru K, Radebold A, Panjabi MM, McGill SM. Lumbar spine stability can be augmented with an abdominal belt and/or increased intra-abdominal pressure. *Eur Spine J*. 1999;8(5):388–395.
31. Sahrmann S. *Diagnosis and Treatment of Movement Impairment Syndromes*. St. Louis, MO: Mosby; 2001:69, 73.
32. Flanagan SP, Salem GJ. Bilateral differences in the net joint torques during the squat exercise. *J Strength Cond Res*. 2007;21(4):1220–1226.

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Address correspondence to Oh-Yun Kwon, PhD, PT, Department of Rehabilitation Therapy, The Graduate School, Yonsei University, 234 Maji-ri, Hungup-myon, Wonju, Kangwon-do 222-710, South Korea. Address e-mail to [kwonoy@yonsei.ac.kr](mailto:kwonoy@yonsei.ac.kr).